DETAILS OF THE VARIOUS WINDS, WITH EXPLANATIONS SUGGESTED BY VAN BEMMELEN

The west monsoon shows components of motion from the north at the earth's surface, but from the south above 1 km. It is controlled by the Australian low-pressure center, the isobars of which over western Java trend about SW.–NE. Friction at the earth's surface determines the direction from north of west across the isobars, but relative lack of friction aloft allows air movement there more nearly parallel to the isobars, with the result that the air flows from points somewhat south of west.

The east monsoon also shows components of motion from the north at the earth's surface, which is contrary to expectation, since the great control of the east monsoon is the Australian high-pressure center, which should produce winds with southerly components. The discrepancy is explained on the basis of the dominance of the sea breeze over the land breeze on the north coast of Java during the season of the east monsoon. Above the surface wind, as above the west monsoon, the expected components from the south are found, in the bottom of the trade wind.

The trade wind, above the monsoons, is a great drift from points south of east, reaching its maximum thickness and altitude and velocity during the Southern Hemisphere summer (see the February column in fig. 1), and maintaining a winter altitude of but 3 km. plus. Its velocities are moderate throughout the year except in its upper levels in February. Bearing in mind the fact that in the Australian low pressure above a certain level the direction of the gradients must be reversed and that a flow of air in directions toward the south of west about parallel to the isobars is therefore to be expected, it is at first surprising to find the persistent movement toward the north of west. Van Bemmelen explains this seeming anomaly as being the result of friction due to the upthrust of convectional currents (with components of motion from the west), the braking effect thus produced being sufficient in the lower part of the easterly winds to direct them across the isobars down the gradient toward the Equator. The gradual disappearance of this effect toward the upper part of the current at all seasons, and the taking on of its character as a year-round current from directions north of east, is explained on the basis of the failure of convection to reach the great heights.

The trade wind, it will be noted, descends to much nearer the earth for the months May to November, and replaces the west monsoon in the 2 to 3 km. levels. It now flows on the gradients northwest of the Australian winter high pressure the isobars of which over Java trend ENE–WSW, and the observed large angles which the winds make with the isobars are again explained as the result of friction.

The antitrade (or pseudoantitrade) comes next above the trade, and flows throughout the year (except in June at 13 to 16 km.) as a deep and for the most part swift stream from directions north of east, a nearly frictionless motion parallel to the isobars, these being in one half year the isobars of the upper portion of the Australian cyclone and in the other half those of the Australian anticyclone. Over Java both systems trend about ENE–WSW. The name pseudoantitrade is provisionally applied to this wind because of uncertainty as to whether it really is a part of a great poleward outflow or merely the local manifestation of the high-altitude equatorial air stream. This point will be referred to presently.

The upper trade wind, not quite so strikingly shown in the diagram as those hitherto noted, nevertheless can be traced as a flow from the east with distinct components from the south. From October to February it occupies the very high levels (18 to 22 km.) and in the opposite half year much lower levels, reaching in June the 13-km. level. Its velocity decreases, broadly speaking, as its southerly components increase, or toward the bottom of the flow. In its upper portion it is seen to merge gradually, in respect to both velocity and direction, into the east wind at the upper limit of observation.

This upper trade wind represents a reversion to air movement from the south of east, as already noted for the case of the trade wind. Friction is assigned as the cause. It will be seen that in the months May to September a high-altitude west wind blows, a deep stream in contact both above and below with air moving from easterly directions. To the drag thus caused is assigned the failure of the easterly winds to flow parallel to the assumed trend of the isobars (from N. of E. to S. of W.) in those levels.

The Krakatoa wind has been referred to above, indirectly. It is regarded as a wind distinct from the upper trade. It constitutes the highest flow observed, is persistent except in June, July, and August when the high-altitude west wind, reaching its greatest height, disturbs the base of the Krakatoa current, which maintains a high velocity except in those months when it seems to be affected by friction with the high-altitude west wind, May to September. The name of this highest stream is assigned because of its correspondence in altitude, direction, and velocity with the observed travel of the Krakatoa dust. The similarity in velocity is not shown in the diagram, hence it is of interest to note that in two cases the Batavia flights reached the 30-km. level and showed high velocities to exist there, as follows:

Sept. 12, 1912:
29.5 km., 40.4 m/s.
30.5 km., 34.3 m/s.
Mar. 2, 1913:
29.0 km., 47.4 m/s.
30.0 km., 43.1 m/s.

The high altitude west wind, with distinct components from the south, shows only moderate speed except at 18 to 20 km. in June, when it averages 10 m/s. Its *raison d'etre* is very difficult to assign. The suggestion is advanced that it seems to be connected with the great west-to-east circulation of the Southern Hemisphere, since it displaces the easterly flow over Batavia in those months when the circumpolar whirl of the Southern Hemisphere spreads northward—in other words, it waxes and wanes with the migration of the sun. The conception thus is, that during the Southern Hemisphere's winter the rotating disk of air which is felt at the earth's surface in the Roaring Forties and southward, to the north may overspread the tropical high pressures aloft and extend its wedge into the high altitudes at least as far north as Java. An evident difficulty with this interpretation is recognized in the southerly components shown by this wind, which indicates that in those altitudes in those months at least locally the gradients slope toward the Equator—not away from it, as would be necessary to cause the poleward flow of air demanded by the indraft of the trades at the earth's surface. This point will be touched upon again.

We now turn to the substance of van Bemmelen's discussion concerning the relations of the air streams described above to the general intratropical circulation. The discussion is mainly centered upon the significance of the equatorward components of motion in the upper trade and the high-altitude west winds, and of the poleward components in the current of the antitrade.

Van Everdingen has maintained[5] that a poleward outflow must take place at a much higher altitude than

[5] Tijdschrift K. Aardrijkskundig. Gen. Amsterdam, 1918 and 1919.

those occupied by the antitrade, say at 20 to 30 km. The Batavia observations show, however, at 20 to 23 km. for the Southern Hemisphere summer a distinct component from the south of east—an inflow. In the opposite season, the high-altitude west winds at these heights show still more marked southerly components. Moreover, a major objection to supposing that an important poleward flow exists at great altitudes lies in the relative densities of the air at these and at lower levels, and the consequent inability of such a flow to accomplish the poleward displacement of enough air to drain away the much denser indraft occurring in the lower levels. (See Table 1.)

Furthermore, the view that because of the earth's rotation the inflow of the trades becomes the outflow of the antitrades *in a continuous belt round the globe* connotes a grotesque isobaric system. For, at the altitude of the antitrade, motion is necessarily very close to the isobars. Hence on the assumption of a continuous belt of antitrades, pressures in the equatorial belt would have to decline endlessly toward the west—an impossible condition.

Van Everdingen[6] and Shaw[7] arrive at the conclusion that the belts of high and of low pressure aloft are not continuous, but break up into centers strung along their general axes. Shaw, by computation for the 8-km. level in the Northern Hemisphere finds high pressure centers at about 20° N. latitude over Central America. northern Africa and southern Asia, and on the basis of the necessarily resulting anticyclonic winds infers the transfer of air from the equatorial east wind into the antitrade "as through a gear drive." Van Bemmelen, pointing out that the equatorial cirrus level lies close below the level of maximum poleward displacement of air over western Java (see Table 1) assembles data on the average stream lines of equatorial and intratropical cirrus as shown below in the maps for the half years (fig. 3). These average flows, though unavoidably based on fragmentary data (Table 2), are those which would result from Shaw's computed pressure system for the 8-km. level, and suggest that similar high-pressure centers aloft exist south of the Equator also.

TABLE 1.—*Relative displacements of air in layers 1 km. thick up to 24 km., by months.* (Van Bemmelen)

The heavy line separates winds with easterly components from winds with westerly, and the broken line northerly components from southerly.

(Relative displacements = 10 × wind velocity in m/s × density of the air)

Km.	J	F	M	A	M	J	J	A	S	O	N	D
24	7	5	3	2	0	0	0	0	1	3	6	8
23	7	4	3	1	0	0	1	0	0	2	4	7
22	6	4	2	1	1	2	2	1	1	2	5	9
21	6	2	1	1	2	3	3	2	1	2	6	8
20	4	1	1	2	3	8	4	2	1	3	7	8
19	5	2	0	2	5	9	5	2	0	5	9	9
18	7	4	1	0	3	11	3	1	6	7	10	10
17	13	10	7	1	3	6	3	11	14	13	14	10
16	18	18	8	3	3	3	18	22	21	18	14	13
15	17	22	18	2	5	7	27	36	27	20	16	14
14	18	22	18	8	12	10	34	44	28	18	16	18
13	20	23	18	10	10	13	43	45	33	15	15	20
12	16	18	13	10	8	13	39	44	31	13	5	16
11	14	12	9	9	9	18	36	39	33	15	6	12
10	12	12	11	7	10	19	34	41	34	16	5	13
9	11	13	11	7	14	20	34	37	33	19	4	11
8	12	13	11	6	17	22	32	34	30	22	2	12
7	7	9	7	5	17	22	32	32	27	22	2	9
6	7	4	0	3	16	24	22	24	22	21	8	7
5	13	11	6	3	17	20	19	14	14	19	14	6
4	20	20	10	6	18	16	14	16	9	21	16	7
3	30	36	16	7	22	13	12	8	15	31	17	13
2	37	47	22	11	29	17	20	20	26	31	14	29
1	37	55	25	8	24	22	28	33	34	24	14	32
0.1	22	23	13	8	5	12	14	12	14	22	17	17

[6] Loc. cit.

[7] Nature, July 21, 1921.

TABLE 2.—*Average stream lines of Cirrus clouds.* (Van Bemmelen

[..........no data]

Station	Latitude	Longitude	Motion from		
			Winter	Summer	Year
amoa	-13.5°	172° W.	W. 9° N, Dec.-Feb.	W. 33° N. June-Aug	S.
Hawaii	19	155	....	....	W.
Mexico	19-33	100	W. 57° S. Dec.-Feb.	E. 36° N. June-Aug.	
San Jose	10	84	E. 3° N. Dec.-Feb.	E. 10° N. June-Aug.	
Habana	23	83	W. 15° S. Dec.-Feb.	E. 26° N. June-Aug.	
Washington	39	76	N. 79° W. Oct.-Mar	N. 77° W. Apr.-Sept.	
Lesser Antilles	14	62	E. 7° S. Dec.-Feb.	E. 30° S. June-Aug.	
Paramaribo	6	55	E. Dec.-Feb.	E. 2° S. June-Aug.	
Atlantic Ocean	25-30	30	....	SW. Apr.-Sept.	
Fayal	39	29	WSW. Winter	NW. Summer	
Square 3	0-10	20-30	E. 51° S. Dec.-Feb.	E. 12° N. June-Aug.	
Square 39	10-12	20-30	W. 46° S. Dec.-Feb.	E. 17° S.	
Cape Verde	15	25	....	SE. Summer	
Ascension	-14	8	....	....	NE.
San Fernando	36.5	6.5	W. 30° N Dec.-Feb.	W. 1° S. June-Aug.	
Congo	-5	14 E.	....	....	E. 37° S
Johannesburg	-27	28	Dec.-Feb	W. 8° S. July-Sept.	
Mauritius	-20	57	N. 80° W. Dec.-Feb.	N. 39° W. June-Aug.	
	16-21	....	N. 67° W. Dec.-Feb.	S. 59° E. June-Aug.	
	12-16	....	N. 33° E. Dec.-Feb.	N. 65° E. June-Aug.	
Arabian Sea	8-12	65	N. 82° E. Dec.-Feb.	S. 54° W. June-Aug.	
	4-8	....	N. 58° E. Dec.-Feb.	S. 39° W. June-Aug.	
	0-4	....	N. 34° E. Dec.-Feb.	S. 82° W. June-Aug.	
Madras	13	80	S. 13° W. Nov.-May	E. 8° S. June-Oct.	
Allahabad	25.5	82	S. 86° W. Jan.-Mar.	E. 27° N. July-Sept.	
Vizagapatam	18	83	S. 4° W. Nov.-May.	E. 18° N. June-Oct.	
Calcutta	22.5	88	S. 84° W. Jan.-Mar.	S. 14° E. July-Sept.	
Batavia	-6	107	E. 1° N. Dec.-Feb.	E. 25° N. June-Aug.	
Pontianak	0	109	E. 5° S. Dec.-Feb.	E. 27° N. July-Sept.	
Manila	15	121	E. 66° S. Dec.-Feb.	E. 12° N. June-Aug.	
Zikawei	31.5	121	W. 1° S. Dec.-Feb.	W. 45° N. June-Aug.	

Sources: Batavia and Pontianak: Proc. R. Acad. Amsterd., Apr. 26. Samoa: G. Angenheister in Nachr. Gött., 1909. Arabian Sea: Quart. Jour. Roy Met. Soc. 1893. India: Indian Met. Memoirs, IV, 8. Atlantic Ocean: W. Peppler in Beitrage zur Phys. d. fr. Atmos. Band. 4. Remaining observations from: Hildebrandson and Teisserenc de Bort, Les Basses de la Météorologie Dynamique, Nova Acta Upsala. Ser. 4, vol. 5, no. 1.

The indicated equatorward displacement of the high pressure centers at the cirrus level as compared with their positions at the earth's surface (it is seen to be of the order of 15°) coincides with the views of Teisserenc de Bort and of Exner.[8] W. Peppler finds for the Atlantic Ocean and for Africa that at 12° N. latitude the pressure at 10 km. is about 4 mm. higher than over the Equator. Hence at this level there still exists a belt of equatorial low pressure. The conception thus is that the trade wind air rising from the earth's surface gets into the anticyclonic circulations, and flows thence, locally on the appropriate sides of the high-pressure centers, into higher latitudes. Such a flow may well be the great antitrade stream found above Batavia. This assumption is supported by the consideration that the tropical high pressure centers, not yet extinguished at 10 km., may persist to much greater altitudes in all tropical regions where convection is the rule. Thus at Batavia this elevation would be some 17 km. Locally also, a part of this originally trade wind air must flow toward the contracting remnant of the equatorial low-pressure belt that is still to be found between the not yet completely merged high-pressure centers. The example of this over Batavia would be the upper trade wind, or pseudo upper trade, as van Bemmelen calls it. As between the inflows and outflows, the latter must greatly exceed the former, though the outflows are diminished by the amount of air that rises into still higher levels.

To these anticyclonic circulations in the cirrus level and above is assigned also the important function of furnishing the driving force for the great and swift stream of air which flows, in the highest altitudes to which observation extends, in a more or less meandering course from east to west along the Equator, as described by meteorologists from Ferrel onward. These rotations thus not only transfer air outward to feed the antitrade flows,

[8] Loc. cit., p 177.

but inward to some extent also, thereby transferring to the so-called Krakatoa wind the energy of the inflowing air streams from higher latitudes. To apply the imagery of Shaw in this connection also, the tropical anticyclones in the high altitudes act as so many gear pumps for the operation of the high-altitude east-to-west current along the Equator. The competence of these gigantic pumps to perform the several functions assigned to them is indicated by van Bemmelen's table of displacements already referred to.

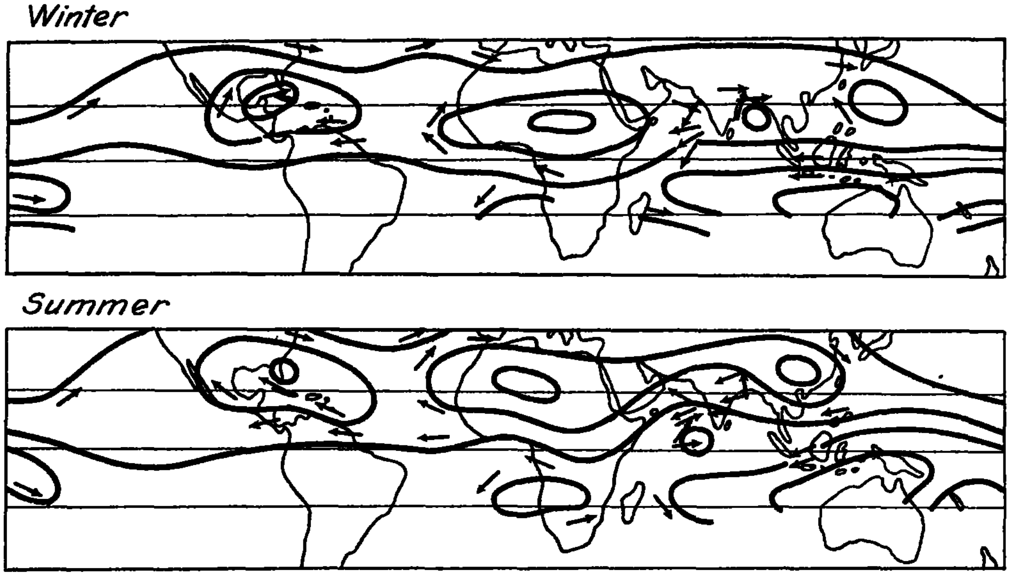

FIG. 3.—Lines of flow of cirrus drift. Reproduced from MO. WEATHER REV., February, 1922, p. 91. See Table 2 of the present paper for data

MITCHELL ON WEST INDIAN HURRICANES AND OTHER TROPICAL CYCLONES OF THE NORTH ATLANTIC OCEAN[1]—A REVIEW

551.515 (261.1) (213)

By ALFRED J. HENRY

The publication under review is the third of the series of memoirs by Weather Bureau officials devoted exclusively to a study of tropical cyclones which at times invade the southeastern United States. It may be helpful at this time briefly to review the two earlier publications[2] and to refer to a Signal Service publication[3] containing the first official comment upon West Indian hurricanes put forth by the Federal weather service.

This publication, although based upon but 10 year's observations, brings out with remarkable clearness most of the essential facts with respect to the distribution and origin of West Indian hurricanes. The following statement with respect to their origin is significant: "An almost entire absence of reports from the region east of the Windward Islands prevents the tracing of storms to their place of origin."

Garriott's treatment of the subject in Bulletin H is descriptive and historical rather than theoretical, although he gives some space to the theorizing of others. His viewpoint is essentially that of the forecaster and he therefore treats the premonitory signs of the approach of a cyclone rather fully. The historical aspect is also fully considered even to reproducing Poey's list of hurricanes in the West Indies from 1493 to 1855. At least 60 per cent of the space in the bulletin is devoted to a description of individual storms, first by months and again without much regard to the chronological arrangement of the storms, and finally 27 quarto pages are devoted to local records and descriptions of hurricanes drawn from the archives preserved in the islands of both the Greater and the Lesser Antilles. The example he set is a difficult one to follow in these days of economy and high cost of printing; indeed, the utility of much of the word pictures of experiences in tropical cyclones may well be questioned.

The next memoir, that by Dr. O. L. Fassig, was issued in 1913. It discusses the occurrence of tropical cyclones from a statistical viewpoint, omitting lengthy descriptions of severe storms except in the single case of the August, 1899, storm, which passed directly across Porto Rico and was carefully observed at a number of points in the several quadrants of the cyclone. Both Garriott and Fassig depended for their paths of tropical storms upon the Forecast Division series of daily weather maps as constructed from reports received by telegraph and cable.

Mitchell's studies differ from those of his predecessors in that he replotted the paths of all tropical cyclones of which he could find evidence within the period 1886–1923, using in addition to the Forecast Division charts another series of charts, viz, those taken over from the Hydrographic Office of the Navy and later continued in the Marine Section of the Weather Bureau from mail reports of ships' observations in the North Atlantic and adjacent waters. He was thus able to plot a greater number of storms than did his predecessors, but the outstanding feature of his work was the extension of the paths of storms picked up in or near the Windward Islands far to the eastward, and thus he completely confirmed the opinions expressed by several writers thirty-odd years ago to the effect that the origin of August and September storms would be found in the vicinity of the Cape Verde Islands. Viñes especially gave the reasons why cyclones should develop in the vicinity of the Cape Verde Islands[4] in August and not in other months.

[1] Mitchell, Charles L., "West Indian hurricanes and other tropical cyclones of the North Atlantic Ocean." Mo. WEATHER REV. SUPPLEMENT No. 24, Washington, 1924.
[2] Garriott, E. B., "West Indian hurricanes," W. B. Bull. H., Washington, 1900, and Fassig, O. L., "Hurricanes of the West Indies," W. B. Bull. X, Washington, 1913.
[3] Dunwoody, H. H. C., Summary of International Meteorological Observations, Washington, 1893.

[4] Viñes, Benito, S. J., "Investigations of the cyclonic circulation and translatory movement of West Indian hurricanes." W. B. No. 168, Washington, 1898, pp. 24-25.